In: Proceedings of the 1994 TAPPI Recycling symposium; 1994 May 15–18;
Boston, MA. Atlanta, GA: TAPPI Press; 1994: 225–228.

Expanding Research Horizons: USDA Forest Service Initiative for Recycled Paper Technology Development

Theodore H. Wegner
Assistant Director

USDA Forest Service
Forest Products Laboratory[1]
Madison, Wisconsin U.S.A.

Theodore L. Laufenberg
Research General Engineer

USDA Forest Service
Forest products Laboratory
Madison, Wisconsin U.S.A.

ABSTRACT

The landfill crisis is posing a great environmental challenge to the United States: What are we to do with the ever-increasing accumulation of waste products? In response, the USDA Forest Service has undertaken a major research program aimed at developing systems and technologies for more complete and efficient use of recovered paper, paperboard, and wood waste. This report describes studies on pulp and paper recycling in five problem areas: paper and fiber sorting technologies, deinking and contaminant removal, pulp bleaching technologies, restoration of papermaking properties of recycled fibers, and performance characteristics of recycled paper.

KEYWORDS

Recycling, paper, fiber, deinking, bleaching

INTRODUCTION

The enormous and evergrowing accumulation of waste products has become critical. The United States has been attempting to store 430 million cubic yards (329 million cubic meters) of municipal solid waste (MSW) into landfills annually. In the next 15 years, 75 percent of all landfills will be closed; by 2000, there will be a massive shortage of disposal capacity.

Paper and wood form the largest single component of MSW. The rate of recovery of these materials has been low. Of the approximately 85 million tons of paper and wood wastes generated in 1990, about 29 million tons were recovered; 56 million tons were disposed of, mainly through landfilling. At this rate, an estimated 65 million tons of paper and wood wastes will be landfilled or burned as waste by 1995. By 2000, the Environmental Protection Agency (EPA) estimates that the United States will generate 216 million tons of MSW. If the recovery and recycling rates do not increase, the portion of paper and wood destined for landfills or other means of disposal will be about 94 million tons.

Although local, state, and federal governments have passed many recycling laws, they have failed to support the research needed to develop technologies for converting waste to high quality products. Using current technologies, it is more costly to manufacture products from waste materials compared to virgin materials. Consequently, industries are reluctant or unable to use waste materials. For example, private industries in Wisconsin have solicited only $6 million of $30 million available for initiatives to integrate more postconsumer waste into manufactured products.

In addition to finding ways to lower the cost of manufacturing products with recycled materials, research is needed to develop products that conform to established codes and standards. Postconsumer and industrial waste is much less uniform than virgin material and poses special problems in the manufacturing process.

For the past 2 years, the USDA Forest Service has undertaken a major research program aimed at developing systems and technologies for more complete and efficient use of recovered paper, paperboard, and wood waste.

RESEARCH PROGRAM OVERVIEW

Forest Service research on recycling is being led by scientists at the Forest Products Laboratory (FPL) in cooperation with universities, other research institutes, industry, and interest groups. The major areas of focus are as follows:

- Pulp and paper recycling technologies–Technologies for sorting fibers, deinking and removing contaminants, restoring papermaking properties of recycled fibers, brightening pulp, and assessing the performance characteristics of recycled papers.
- Nonpaper recycling technologies—Dry-form and wet-form processes for making reconstituted wood products from fibers, flakes, chips, or particles; development of wood–plastic and wood-cement composite products.
- Housing components from recycled materials—Technologies for making reconstituted wood products and wood–nonwood composites; regrading methods for reusing old lumber; development of performance criteria and standards, studies on economic feasibility of technologies.

[1]The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

- Recycling of contaminated wood—Methods for quick identification of chemical treatments on or in recovered wood; recycling options for chemically treated wood; environmentally acceptable methods for generating energy from treated wood; economic models for recycling or disposal options.
- Economic assessment of recycling technologies—Assessment of economic and environmental impact of new systems for recycling paper and wood.

PULP AND PAPER RECYCLING TECHNOLOGIES

This report will focus on pulp and paper recycling technologies. Studies are addressing several technical challenges: (1) the lack of adequate process technologies for cleaning, deinking, and screening, (2) the need for innovative product concepts that increase the use of postconsumer wastes, and (3) the altered strength and appearance characteristics of products made from recycled fiber compared to those made from virgin fiber.

Paper and Fiber Sorting Technologies

The paper industry currently recovers and uses old newspapers (ONP) and old corrugated containers (OCC) very effectively. Jaakko Pöyry recently forecasted a major shortage of these recovered grades by 1998 (1), which would inhibit recycling operations from functioning at full capacity. Perhaps the most visible and economically viable segment of the paper resource that requires new harvesting technology is printing and writing (P&W) paper. According to a recent report by Franklin Associates, Ltd. (2), P&W paper currently contributes more to MSW than does either ONP or OCC. If the rate of recovery of P&W wastepaper is not improved, by 1995 this waste will total 39% more than ONP and OCC combined. The increasing load of P&W wastepaper is likely to attract the same level of State regulatory attention now focused on ONP and OCC.

Approximately half of P&W wastepaper is generated by offices; the other half, by households. About 60% of the office P&W wastepaper can be readily and reliably sorted into standard office paper grades. The remainder of office paper as well as household paper is mixed and contaminated. This paper represents an annual resource of 12 million tons, currently valued at $50 to $120/ton, that is not being used because its recovery is too labor-intensive. At some level of mixing and contamination, manual methods of sorting paper become impractical. The technology necessary to recover paper from seriously mixed and contaminated sources has not been developed.

The primary aims of research are to determine criteria for differentiating mixed papers and to develop economical methods for sorting material into uniform and consistent groups. Studies are focused on

- identifying wastepaper properties and attributes that may serve as a basis for sorting,
- reviewing current separation methods and mechanisms,
- assaying types of paper in household waste streams, and
- testing new separation and sorting methods.

Profitable recovery of high-value fractions of P&W paper will greatly enhance the potential for successful reuse of this and other mixed contaminated paper.

Deinking and Contaminant Removal

In addition to problems associated with sorting, the very nature of recycled fiber presents a challenge to papermakers. Wastepaper contains adhesives, fillers, inks, dyes, metal foils, plastics, and dirt. New approaches are needed to separate these contaminants from recycled fiber. Current separation methods, which separate particles on the basis of size and density, are not adequate for recycled fibers. Many wastepapers contain contaminants that are similar in size and density to the fibers, such as nonwettable synthetic adhesives (“stickies”). New processes and improved process configurations need to be developed for separation equipment.

Biological processes can also be used to separate paper fibers from ink and other contaminants. Biological processes generally facilitate the removal of contaminants, but they can also affect fiber drainage, strength properties, yield, and slime accumulation. Specific research aims include the following:

- to explore mechanisms that affect shear-field separations of synthetic adhesives and binder-containing inks by quantifying the effect of impurities and controllable process variables, including enzyme treatment of pulp slurries,
- to develop fundamental understanding of new principles, including enzymatic approaches, that could be used for new separation processes,
- to optimize enzymatic activity by determining the mechanisms by which enzymes enhance pulp freeness and removal of noncontact ink by flotation,
- to explore fundamental characteristics of toners to understand why wastepaper with tones is easily recycled, and
- to determine the extent to which enzymes such as cellulases and lipases or other microbial processes can facilitate the removal of contaminants and deinking.

Pulp Bleaching Technologies

New environmental regulations are shifting production away from chlorine-based bleaching processes. Technologies designed to meet new environmental regulations for the bleaching of virgin fiber will likely be applied in recycling. However, the unique properties of recycled fibers will require considerable modification of these technologies as well as development of new technologies.

Studies are addressing four fundamental obstacles to effective and environmentally safe bleaching of recycled fibers: feedstocks with mixed lignin content, photoreversion, color stripping. and physical aggregation of cellulose.

Feedstocks with mixed lignin content.

Fibers in mixed P&W paper vary in lignin content. Even after sorting, many higher paper grades include significant admixtures of high-yield pulp fibers. Selective delignification or effective lignin-retaining bleaching will be needed to upgrade these materials for second-cycle use. One option for handling feedstocks with mixed lignin content is to remove the lignin under oxidative conditions prior to brightening. This process makes the material more homogeneous and easily brightened, and it also minimizes the likelihood of photoreversion during the second cycle. However, this process would result in the loss of some fiber mass and would require additional chemicals. In addition, any process designed to remove small quantities of weight-percentage of lignin must be highly selective to avoid damage to cellulose fibers.

The least expensive oxidant for delignification is oxygen. Current research is aimed at more selective and effective utilization of oxygen in delignification using polyoxometalates. One research possibility is using polyoxometalates and oxygen to delignify OCC. The lignin content of fibers used to manufacture OCC is 100% to 200% higher than that in paper-grade chemical pulps. Consequently, OCC fiber requires considerable delignification prior to brightening. Once a substantial amount of lignin is removed, the fibers might be combined with Virgin brownstock and bleached accordingly.

Photoreversion.

The lignin component of high-yield pulp fibers and the cellulosic component of bleached chemical pulps are subject to photoreversion or yellowing. These chromophores, generated during the first cycle of use, differ from chromophores in virgin fibers. Research is focused on (1) identifying and characterizing chromophores in wastepapers manufactured from high-yield and chemical pulps and (2) studying chromophore reactivities using model compounds to find the most effective methods for degrading and removing the chromophores. This work is an extension of efforts already underway in the FPL Chemistry and Pulping Research Work Unit to elucidate the structures and degradation pathways of chromophores in virgin high-yield pulps.

Color-stripping.

Mixed office waste includes dyed fibers. The color-stripping of recycled fiber is complicated by the wide range of chemical structures of synthetic dyes. Dyes in wastepaper have traditionally been removed with relatively inexpensive chlorine compounds. Current alternatives, although often effective, are considerably more expensive. In a joint effort with dye manufacturers and papermakers. the FPL is taking a life-cycle approach to the manufacture, use, and removal of dyes. The study is aimed at removing or degrading dyes by enhancing their susceptibility to inexpensive yet highly specific chemical or biochemical treatments.

Physical aggregation of cellulose.

The conditions used to manufacture paper from virgin fibers result in cellulose aggregation. During the latter stages of papermaking, the elevated temperatures used in drying and drying itself cause physical aggregation of cellulose and hemicelluloses, which reduces the accessibility of pulp chromophores to bleaching chemicals. The accessibility of chromophores in representative unbleached paper products needs to be determined experimentally. Barriers to accessibility can be removed through enzymatic treatment, milling, decrystallization, or other techniques. As chromophores are exposed, improvements in the rate and completeness of bleaching reactions can be determined. Selected bleaching agents can be used to determine the degree to which diffusion and mass transfer slow or impede the bleaching process. In practice, accessibility might be improved using chemical or biochemical treatments, some of which may overlap with treatments used to restore papermaking properties.

Restoration of Papermaking Properties of Recycled Fibers

The final stage of papermaking, drying the sheet at relatively high temperature, hardens the surface of fibers and stiffens their internal structure. These effects must be reversed if the fiber is to be reused for papermaking. Hardening of the surface limits interfiber bonding, and internal stiffening reduces the conformability of the fibers. Both effects can limit the consolidation of the paper web.

Recent literature indicates that the fundamental problem encountered when making paper from recycled fibers is loss of relative bonded area. Traditional methods of treating recycled fibers with alkali and/or mechanical beating have been only partially successful in restoring the original papermaking potential of the fibers.

Research is aimed at characterizing the effects of process variables on the structure and transformation of pulp fibers as they pass from one stage to the next in a recycling operation. Established material science methodologies—diffractometry, solid-state 13C nuclear magnetic resonance, Raman spectroscopy, and electron microscopy—are being explored for characterizing the secondary and tertiary structures in cellulosic fibers.

Changes in structure affect the void volumes within the fiber cell wall. Re-establishment of the original volumes is critical to restoring fiber flexibility and conformability. Studies are aimed at using enzymatic treatments to increase the size of pores in the cell wall of secondary fibers. Data from studies on structure and enzyme treatments will be used to develop a comprehensive computer model of the response of cell wall polymers to hydrodynamic forces and chemical, mechanical, or enzymatic treatments. The model may be used for further experimental validation and for guiding rapid and effective technology changes in paper recycling.

Performance Characteristics of Recycled Paper

Papermakers are able to produce a remarkable array of products with very different properties by controlling the furnish, additives, and process. When postconsumer fiber is introduced into fine paper grades, control of one of these variables is lost: the furnish of recycled fiber is a mixture of various species pulped by various means. If the product is to remain consistent, the other variables—additives and process—must be adjusted to compensate for changes in furnish.

To obtain consistent products, papermakers must be able to characterize all essential performance aspects of a particular product or grade of paper. At present, characterizing subtle differences that affect paper performance challenges the limits of our technology.

Changes in the surface energy of secondary fibers and the presence of contaminants can significantly affect the friction properties of the paper product. Reduction of the coefficient of friction can cause problems with roll-winding, printing, sheeting, and feeding of photocopiers. Neither the measurement of friction nor the mechanisms of its effect are well understood. Studies will address this issue through developing methods, analyzing surface chemistry, and measuring physical properties of the surface. Specific aims are as follows:

- to understand the mechanism of friction-effect in paper and develop a fundamentally sound means for specifying friction properties,
- to provide a basis for quantifying the “feel” of paper, which will elucidate the perceived “limpness” of some recycled paper,
- to develop a standard for curl and hygroexpansivity by relating stiffness to fiber furnish, moisture content, and papermaking variables, and
- to develop computer models to measure behavior of layered structures and quantify behavior of furnish mixes.

CONCLUSION

The Forest Service, by way of Congressional mandates, must take a strong role in recycling research. The initiatives described in this report quicken the pace toward solving the fundamental and applied problems that are key to making major shifts in the rates of recycling. Developing technologies for recycling will reap both short-term and long-term benefits in reducing dependence on landfills for disposal of waste. Research on recycling can turn wastepaper and waste wood from a national disgrace to a valued resource.

LITERATURE CITED

1. M. Cesar, “Wastepaper—A Regional Commodity.” In: *Proceedings of Wastepaper III, Pulp and Paper Week,* May 20-22 (1992).

2. Franklin Associates, Ltd., “Characterization of Municipal Solid Waste in the United States: 1992. Update,” U.S. Environmental Protection Agency, Office of Solid Waste, Washington, D.C., 1992.